The average date for the whole period is April 8, but the chief interest lies in the averages for 10-year periods. For convenience these were taken for the 50 years from 1872 to 1921, inclusive, and show for the decades in Table 2. For comparison Table 2 also shows the temperature means of the three months, January, February, and March, at Oswego, N. Y., which were averaged for each year and then 10-year averages worked out. These resulted as follows:

TABLE 2.—*Mean dates of opening and temperatures at Oswego, N. Y.*

Period.	Mean date.	Temperature at Oswego, N. Y.
1872–1881	Apr. 13	27.4
1882–1891	Apr. 10	24.8
1892–1901	Apr. 9	25.0
1902–1911	Apr. 4	26.0
1912–1921	Apr. 5	25.5

The Oswego station is about 30 miles from the lake. With the exception of the first decade the results conform to the theory that the lake is an indicator of the intensity of the winter cold and the earliness of spring combined. One factor which may in part be responsible for discrepancies is that of relative cloudiness and sunshine. Central New York has an excessive amount of cloudiness in winter but the amount, especially in March, is very variable, and it is possible that in some cases where the temperatures were mild the excessive cloudiness prevented the melting of the ice as rapidly as would have occured with normal sunshine. The reverse might also have been the case in some instances, but generally speaking, the melting of the ice seems to be a function of the temperature during the winter and early spring and thus to indicate, in a way, the weather character.

This would seem to indicate that although the lake opened this spring earlier than in any year since 1880, and more than three weeks earlier than the average date, there is a tendency shown in the last 10 years toward a return toward average conditions.

Incidentally, it may be noted that in the record-breaking mild winter of 1889–90 the ice in the lake broke up several times, the last date being March 27. The two years when the lake made its record for late opening, 1873 and 1885, both had hard winters previously, but in 1918 and 1920, when the winters were equally severe, the lake opened little if any later than the average, due to unusual warm periods late in March. The real effect can only be seen by averaging a period at least a decade in length.

The lake records are now kept by Fred Beebe, of Constantia, to whom, and to Miss J. M. Smith, of that village, who has the early records in her possession, the author's thanks are due, as they are also to Mr. Julius G. Linsley, official in charge of the Oswego station of the Weather Bureau, who afforded him ready access to the climatological records of the office.

REGISTRATION OF THE INTENSITY OF SUN AND DIFFUSED SKY RADIATION.[1]

551.590.2 : 551.508.2

By A. ÅNGSTRÖM and C. DORNO.

[Stockholm, Sweden, and Davos, Switzerland, December, 1920.]

[Translated by C. LeRoy Meisinger.]

SYNOPSIS.

The pyranometer of A. Ångström has been combined, at the observatory of Prof. Dorno, at Davos, with a recording device consisting of lamp, galvanometer, and a rotating photographic film, upon which the galvanometer deflection is recorded. In this way records are obtained of the total heat radiation from sun and sky upon a horizontal surface at all times of day, and from this record the daily sums are easily computed. In the present paper the recording method is described, the sources of error are discussed, and finally the results from the records at Davos are presented and compared with results of measurements at Washington and with the records of the brightness previously obtained by Prof. Dorno.

Concerning the instrument.—A. Ångström's pyranometer has been described in an earlier number of the REVIEW.[2] The J. L. Rose Co., of Upsala, has, since that time, furnished a somewhat smaller type of this instrument in a slightly simpler form, without the leveling screw, level, or the screen mechanism for cutting off the sun. The constant of the instrument, furnished by the manufacturers, may be quite accurately checked, by first exposing the strips to the sun and sky, and then to the sky alone. These observations combined with a simultaneously made pyrheliometric determination of the solar radiation intensity, I, and the solar altitude, h, enable one to determine the constant by means of the fundamental formula $R=ci^2$, (where R is the radiation intensity, i the strength of the heating current, and c the constant), and the known relation, $c=\frac{I\sin h}{i_1^2-i_2^2}$, ($i^1$ and i^2 being the two heating currents in the two exposures mentioned above).

Small variations of this constant are to be expected since the absorptive power of the black platinum strip and the reflective power of the magnesium oxide are not absolutely uniform for the entire length of the spectrum of the sun and sky. The constant evaluated in this way for the Davos instrument, 12.93, compares favorably with similar measurements on the larger type of instrument, which, in another manner, was found to be 8.61.[3] The instrument proves to be very reliable and uniform neglecting a few very easily removed deficiencies. Numerous trials have been made at the Davos Observatory and a 10-day comparison was made between the two specimen instruments under very favorable conditions. This comparison was made during the period of November 8 to 17, 1920, the registering instrument proving very practicable. In conjunction with these comparison measurements, records were taken over two November and two December decades. The registration apparatus is described in the January, 1921, *Meteorologische Zeitschrift*. With its application the compensation procedure will naturally be neglected, only the swing of very sensitive galvanometers will register photographically; auxiliary tension and damping resistance will not be considered. Both poles of the thermoelement are grounded, but between one of these and the earth the galvanometer is placed and the necessary resistance introduced to diminish the current. On this arrangement, a galvanometer throw of 1 mm. indicates 0.005 gr. cal./min. cm.[2]; a very small correction may possibly be applied to this value, while the constant, c, as has already been mentioned, awaits a more absolute determination, because, further, the relations with larger solar altitudes will be more reliable, and because, finally, the quality of the

[1] Published simultaneously in the *Meteorologische Zeitschrift*, Feb., 1921.

[2] Ångström, Anders: A new instrument for measuring sky radiation. MO. WEATHER REV. November, 1919, 47: 795-797.

bell-glass leaves something to be desired. Even with winter solar altitudes, the width of the photographic paper upon which the galvanometer deflection is recorded, 14.5 cm., does not suffice, and the amplitude of the throw must be reduced by about one-half by the insertion of 1000 ohms resistance, and, occasionally, at the beginning of registration about the middle of November, it is necessary to insert 2000 ohms; the corresponding readings must then be multiplied by the factor 3.05. The zero line is determined in the morning, at noon, and in the evening, by breaking the circuit for ten minutes.

If the instrument is screened off from the sun and sky, the record is only slightly influenced by small variations (only up to 1 mm.) due to the long-wave radiation of the bell-glass and cap, and it appears that warming elevates the line, and cooling lowers it. The evaluation of the curves is managed in the same manner as the evaluation of brightness curves.

The small remaining residuals have three causes: (1) the bell-glass as it has been furnished up to the present is not satisfactorily homogeneous and it even has bubbles of such size that they can be seen readily by the shadows they cast.[3] By exposing the bell-glass and the strips in exactly the same orientation to the solar beam, one obtains quite similar galvanometer swings; but this is not exactly the case if the orientation of the instrument is changed. During the daily registration, errors originate if the instrument remains in a fixed position, and these errors can amount to as much as 4.5 per cent. This error can be reduced to a minimum. (2) With a horizontal exposure of the strips and a very low sun, which, of course, causes the rays to fall in a very slanting manner, there is some radiation which falls between the strips on or in the vicinity of the thermoelements. This also needs improvement, even though a perfect remedy may not be possible. (3) The instrument possesses a certain lag, and does not follow the variations of intensity so quickly as does the photoelectric method. The cause of this is found in the heat capacity of the receiving surface and in the fact that the heat is not transferred instantaneously to the thermo-elements. When one makes use of the chief superiority of this instrument, its registering capability, then the lag becomes important in consequence of the relatively large induction forces opposing the small electromotive force of the thermoelement. By *means of alternate shading and exposing, it is discovered* that in less than the galvanometer's period (scarcely ten seconds) at least 63 per cent of the intensity will be registered, the difference between the incident radiation and the pyranometer reading will be reduced in less than 10 seconds to at least the e^{-1}th part—a definition of the lag which has been applied by Eric R. Miller to his testing of the Callendar recorded and which seems very adequate.[4] The result follows the form of a very steep exponential curve, only about the last seventh of the intensity remaining after about 1½ minutes after screening the instrument. Through this lag, with continuous automatic registration, there originates a small smoothing out of the curve which is hardly apparent on the normal scale (16 mm. to 1 hour) but which is shown by a comparison with the photoelectric record. This third small residual error can hardly be eliminated or corrected.

[3] Later, the Zeiss Co. has furnished for use with the instrument, bell-glasses which have proved almost entirely free from the disadvantages mentioned above.—A. A.
[4] Mo. WEATHER REV., June, 1920, 48: 346.

Results.—As an example of a day's radiation of sun and sky received on a horizontal surface, the curve of November 26, 1920, is offered. On this day there was delicate bright cirro-stratus (cloudiness 3–6), the brightness of the sun varying between bright to very bright. At 9:28 a. m., the sun rose over the mountain, and at 3:12 p. m., disappeared behind the mountain; between 9:48 a. m. and 2:52 p. m., 1,000 ohms were inserted in the circuit, and the circuit broken from 7:57 a. m. to 8:03 a. m., 1:31 p. m. to 1:37 p. m. and 5:20 p. m. to 5:35 p. m. In figure 1 it is seen that on the one hand from 8:00 to 9:28

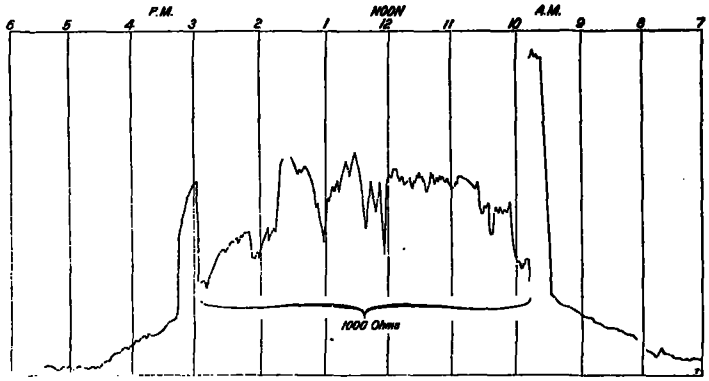

FIG. 1.—Radiation of sun and sky received on a horizontal surface recorded at Davos, Switzerland, on Nov. 26, 1920.

a. m. and from 3:00 to 3:12 p. m., when the resistance was not in, there are scarcely any vibrations in the line; and, on the other hand, during the day, with the 1,000 ohms in, there are sharply marked variations corresponding to the temporary obscurations of the sun. These facts indicate the trustworthiness of the instrument.

In Table 1 are given, in gram calories per square centimeter for the two last decades of November and the two first decades of December, the mean hourly totals (true solar time), the daily sums, as well as the absolute and mean intensity maxima, and for noon, the mean, maximum, and minimum intensity. All of these data are given (1) for all days, and (2) for clear or nearly clear days.

Let us compare next the observations of radiation of a horizontal surface from the sun alone made during the years 1908–1910 on absolutely clear days with the daily sum by the present method. For example, compare November 17, 1920 (neglecting the time the sun was behind the mountain) with the mean of November 15 from 1908 to 1910 (Table 4 of "Studie" [5]), increasing the daily sum by 3.5 per cent in order to bring them to the height of the Smithsonian scale, and calculating 0.04 gram calories per square centimeter per minute for the diffuse sky radiation with a mean solar altitude of 10°. Then one obtains for the pyranometer measurement 185 calories and for the computed values for 1908–1910, 178 calories, the former case being 4 per cent greater than the latter, which is about the same amount as the sun radiation in November, 1920, was in excess of that in 1908–1910. For a similar comparison for December, the result is somewhat different, but is satisfactory. The bright snow cover after December 1, on the mountain heights, increased the diffused radiation by over 60 per cent.

[5] "*Studie über Licht und Luft des Hochgebirges*," Vieweg, 1911.

TABLE 1.—*Hourly and daily totals, maxima and minima of sun and sky radiation on a horizontal surface, in gram calories per cm.² per min.*

I. ALL DAYS.

1920.	(True solar time) hours ending at—										Total	Intensity maximum.		Intensity at 12 o'clock (noon)			Number of normal days.
	8	9	10	11	Noon.	1	2	3	4	5		Absolute	Mean.	Mean.	Maximum.	Minimum.	
Nov., 2d decade	1.22	3.64	19.12	34.80	36.46	34.97	29.66	19.55	6.69	1.34	187.5	1.001	0.700	0.607	0.713	0.435	......
Nov., 3d decade	1.55	4.46	15.41	26.72	29.90	26.73	22.75	24.59	5.71	1.24	149.1	0.695	0.596	0.537	0.648	0.410	......
Dec., 1st decade	1.10	3.87	10.80	19.99	25.04	25.74	20.23	13.96	4.57	0.66	126.0	0.754	0.532	0.452	0.748	0.181	......
Dec., 2d decade	0.96	4.07	13.26	27.55	32.30	33.45	25.11	16.05	5.29	0.89	158.9	0.996	0.702	0.584	0.838	0.332	......

II. CLEAR OR PARTLY CLOUDY DAYS.

1920.	8	9	10	11	Noon.	1	2	3	4	5	Total	Absolute	Mean.	Mean.	Maximum.	Minimum.	Number of normal days.
Nov., 2d decade	1.02	2.81	20.98	38.27	41.33	38.48	32.45	22.22	7.84	1.49	206.9	0.742	0.698	0.675	0.713	0.625	6
Nov., 3d decade	1.35	3.42	18.24	32.19	36.27	34.17	29.67	19.59	6.18	1.53	182.6	0.634	0.608	0.599	0.615	0.582	2
Dec., 1st decade	1.26	3.94	13.94	28.78	36.28	38.94	26.64	19.74	5.98	0.94	176.4	0.754	0.751	0.700	0.748	0.632	3
Dec., 2d decade	0.74	3.41	12.50	29.97	33.96	33.38	26.24	18.12	5.19	1.13	164.6	0.661	0.643	0.616	0.635	0.600	4

Under the influence of cloudiness, the radiation received on a horizontal surface was diminished during the two November decades from 389.5 calories to 366.6 calories, or a decrease of 13.6 per cent. (This represents observations during 71 per cent of the total possible duration of sunshine, as determined by the topographical features around Davos.) Table 6 of the "Studie" shows that the direct solar radiation *a* on a horizontal surface was decreased by cloudiness in November in the average by 59.4 per cent. The calculation of this table is based, however, upon the 10-year means (1899–1908) of records of the Campbell-Stokes sunshine recorder, but the sunny November of 1920 surpassed these means by fully 22 per cent (130 hours as compared with 107 hours). In view of this rather crude calculation, it appears that the radiation value as determined by the solar intensity measured in a clear sky and from the duration of sunshine as measured by the Campbell-Stokes instrument does not disagree widely with the real one; that even the mean total of radiation from clouds is nearly compensated by the diminished brightness of the sun as recorded by the sunshine recorder. This previous experience, which extended only to low solar angles and winter cloudiness, demonstrates that for radiation we can count with similar conditions as for brightness. The total brightness is less dependent upon the brightness of the sun at low solar angles than at high; with low and bright sun, the effect of clouds goes in the direction of increasing the radiation by 10 to 20 per cent. Clouds are most effective when near the sun with high altitude angles. Maxima (an increase up to 65 per cent) occur when the sun suddenly breaks through an opening in high white stratus clouds. With hazy sun (S_1) and bright stratus, the values are quite similar to the normal; with very hazy sun it reaches about four-fifths of normal; with very hazy sun in a valley filled with low, light gray clouds at an altitude of about 100 meters, the value becomes two-thirds, with average snowfall from nimbus, the value is one-half to one-third of the normal. The value is thus less with low clouds than with the high ones, and they are not identical with other conditions under the high valley conditions of Switzerland.

Excluding the sun and the bright sky immediately adjoining the sun, the radiation received from the sky on a horizontal surface amounts to 0.09 with the solar altitude 25°; to 0.08 at 20°; to 0.04 at 10°; and to 0.02 at 0°, all values being gram calories per square centimeter per minute. Even after sunset, the diffuse sky radiation is of measurable intensity. With the appearance of white cumuli or bright stratus at bright or medium bright sun an increase to double or three-fold the normal value is measured, while with very hazy sun, it amounts to only 15 to 30 per cent. With a clear sky, the nocturnal long-wave radiation of the earth at Davos[6] amounts to—

Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.
0.182	0.178	0.183	0.180	0.205	0.216	0.185	0.183

these being mean values from twilight to twilight in gram calories per square centimeter per minute. The assumption that these values of the long-wave earth radiation are also applicable to the day time is hardly to be doubted, as was shown by the observations of A. Ångström at Åvike, in Sweden, during the solar eclipse of August 21, 1914.[7] While the radiation of short-wave length of the clear day sky in the high mountains in winter is only a small per cent of the long-wave outgoing heat radiation, there is a continuous stream of heat moving from the earth to the sky, and this effect is probably also in the average the same in the summer time. The reflection from freshly fallen snow on the mountain slopes amounts, at a solar elevation of 20°, to 69 per cent of the normal sky radiation with a clear sky; this value was determined photometrically in the years 1908–1910 to be about 50 per cent on the average. ("Studie," p. 47.)

For more than 10 years at Washington means of the sun and sky radiation falling on a horiziontal surface, as recorded by the Callendar pyrheliometer, have been measured.[8] These values in comparison with those at Davos show good agreement. For instance, with 27° solar altitude the value of 0.68 gram calories per square centimeter per minute was obtained at Washington on December 22 and at Davos on November 10. And at Madison, Wis., which lies in latitude 43° 5′ as compared with Davos at latitude 46° 48′, and at an elevation of 300 meters as compared with 1,600 meters at Davos, the November mean of eight years of observation scarcely departs from that observed at Davos in the second November decade, so far as the sun at Davos is not obscured morning and evening by mountains. The result is unexpected. Since the solar intensity in high mountains is usually in excess of that of lower elevations (in the foregoing example the solar intensity at Washington was 1.18 and that at Davos 1.38), it must be

[6] MO. WEATHER REV., June, 1920, 48: 349. This is an extended comparison between the Tulipan instrument and pyrgeometer, which shows that the simple Tulipan instrument can be put to the use of determining the nocturnal radiation and at the same time the conditions of cloudiness during the night.

[7] Meteorologische Zeitschrift, 1916, p. 58.

[8] Miller, Eric R.: Some characteristics of the Callendar pyrheliometer. MO. WEATHER REV., June, 1920, 48: 344–347.

concluded either that the diffuse sky radiation at a given place is extremely important (ratio of vertical component of solar radiation to that from sun plus sky was in Washington 0.80, in Davos 0.92) or that the difference lies in instrumental errors, of which a clue might be found in the above-mentioned investigation by Eric R. Miller of the Callendar recorder.

A comparison between the curves of heat radiation and the brightness curves given in the January, 1921, issue of the *Meteorologische Zeitschrift* shows, as one might expect, that the former has a smaller amplitude than the latter. As a rough approximation, to illustrate, the brightness intensity increases in the ratio 1 :1.5 :2 with solar altitudes of 15, 20, and 25°, while the heat radiation increases in the ratio 1 :1.35 :1.5. This point will be discussed later.

In spite of the three small residual errors discussed above, the instrument has proved itself to be a great advance and will probably gain general use. It will serve a useful purpose in many investigations which are of great importance to meteorological advances and which depend upon the interchange of heat between the earth, sun, atmosphere, and space. This will depend also upon a correct understanding of the relations of nocturnal radiation to temperature and humidity and to the type and amount of clouds. Furthermore, the instrument will serve to give the values of "vorderlicht" and "unterlicht" (vertical surface, and horizontal surface exposed downward) in calorie measurements; it will give data on the relations between altitude and optical purity and radiation; and if a suitable bell-glass is perfected it will extend investigations on single parts of the spectrum. The results obtained with this instrument may also be a valuable check on the results obtained with other differently constructed instruments; in order that we may be sure of an experimental result, it seems important that it should appear on the basis of different methods agreeing with one another.

NOCTURNAL TEMPERATURE INVERSIONS IN OREGON AND CALIFORNIA.

551.574:634.1 (794)(795)

By FLOYD D. YOUNG, Meteorologist.

[Weather Bureau Office, Portland, Oreg., Jan. 5, 1921.]

SYNOPSIS.

Not enough attention has been paid in the past to locating crops subject to damage by frost on the more frost-free hillsides; and at the present day the phenomenon of nocturnal temperature inversion is not well understood by most fruit growers. Orchards set out 20 years ago in some of the coldest sections in several fruit districts on the Pacific coast are still being operated at a loss, while others have been removed only during the last two or three years. Detailed records of nocturnal temperature differences on slopes, covering entire frost seasons, are scarce.

Observations of nocturnal temperature inversions, made at Pomona, Calif., and Medford, Oreg., during the frost seasons of 1918, 1919, and 1920, are given in detail and discussed in this paper. Inversions at Pomona during the winter are compared with those at Medford during the spring. Differences in minimum temperature as great as 28° F. were observed between stations at the base and 225 feet above the base, on a hillside at Pomona.

The greatest inversions occur on clear, calm nights, following warm days. The duration of the minimum temperature on the hillside is usually much shorter than on the valley floor below, on account of large fluctuations in temperature during the night on the hillside.

On every hill where observations were made, the data indicate that on clear, calm nights the top of the hill is colder than points on the hillside some distance below.

The temporary vertical distribution of temperature found in the atmosphere over a plain or a valley floor on clear, calm nights, wherein the air temperature increases from the ground up to a height of from 100 to 1,500 feet above the ground, is called "nocturnal temperature inversion."

The steps in the development of a nocturnal temperature inversion may be summarized briefly as follows:

During a clear, calm day the temperature of the ground surface is raised through heat received by radiation from the sun, and the air in contact with the ground is warmed by conduction. This warmed air is forced upward and replaced by cooler and denser air from near by or above, and a circulation is established, which continues as long as the ground surface is warmer than the air in contact with it. Near sunset the air up to a height of a thousand feet or more is very nearly in adiabatic equilibrium.

After the sun goes down, the surface of the ground loses heat rapidly by radiation to the sky and its temperature soon falls below that of the air in contact with it. The surface air cools through conduction of heat into the colder ground, and its density becomes increasingly greater. Its increased density tends to keep it in contact with the ground, where it continues to grow colder and colder throughout the night. As air is a poor conductor and radiator of heat, the temperature of the air a few hundred feet above the ground falls much more slowly, and by sunrise a considerable difference in temperature has developed between the air at the surface of the ground and that a few hundred feet above the ground.

In the case of a valley, with fairly steep slopes on either side, the minimum temperature on a frosty night is likely to be much lower on the valley floor than at points on the hillside, the highest minimum temperature occurring at a height of from 200 to 1,500 feet above the valley floor.

A knowledge of the average and extreme differences in temperature between different portions of the hillsides and the valley floor is of great practical value in deciding where certain crops will be grown. If this information is available, crops most susceptible to damage by frost can be planted at the level on the hillside where the highest minimum temperature is found most frequently, and the colder locations on the floor of the valley can be utilized to grow more frost-resistant crops.

A single season's observations may be misleading, as the nocturnal temperature inversion varies from year to year in the same way that one season's weather differs from another's. At long intervals "freezes" are likely to occur, in which low temperatures are accompanied by high winds, and crops on the hillsides suffer as much, or even more, damage than those on the valley floor.

Temperature inversion [1] also plays an important part in the protection of crops by orchard heating; the extent of the inversion and the amount of wind largely determine what the efficiency of the heaters will be on a given night. A strong wind will prevent the development of a marked temperature inversion by keeping the air at different levels thoroughly mixed; in localities where low temperatures during the growing season usually occur with little air movement, orchard heating can be practiced with greater success than in districts where low temperatures are often accompanied by high winds.

In most of the orchard districts in the Pacific coast States, either through lack of knowledge or through dis-

[1] See Humphreys, W. J.; Frost Protection. MO. WEATHER REV., October, 1914, 42: 562–564.